

DETERMINATION OF BASELINE DATA ON RESPIRABLE
DUST CONCENTRATION FOR SAFETY AND HEALTH
ENHANCEMENT IN SELECTED SMALL AND MEDIUM
INDUSTRIES IN JOHOR

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Abstract

Air pollution has become the major global concern regarding to the harmful health effect, increased morbidity, and mortality especially for particulate air pollutant. However, there is still very limited study that discussed the effects of exposures of dust and particle matters in industry at Malaysia especially respirable dust. This study was focus on the respirable dust concentration and their respirable health symptoms in selected industry. Three (3) case studies had been done as data collection. For each case, several sampling location was chosen for sampling station and several workers was randomly choosen as respondents in assessing the exposure of respirable dust by using personal environmental monitoring (PEM) method. Series of a direct reading measurement for area sampling of respirable dust (PM_{10}), carbon dioxide (CO_2), temperature and relative humidity were also conducted at the same time. Questionnaires were administrated in purposed to determine the respiratory health problem symptoms and supported by lung function test by using spirometer with a standard method of sampling. The result of the study showed most of the workers in paper based mill were exposed to respirable dust when the Time Weightage Average (TWA) result was above the permissible exposure limit which is 5 mg/m^3 and 3 mg/m^3 from Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) standard respectively. From the survey feedbacks, out of 30 symptoms, there are only five symptoms that are significant with the year of exposure. For pulmonary lung function test, there were 81.81% (paper based mill), 53.33% (palm oil mill) and 65.63% for automotive plant were in normal spiro status respectively. Significant reduction was observed in the mean values of Force Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV_1), and Force Expiratory Ratio (FEV_1/FVC) among workers. It is concluded that lung function among exposure workers is impaired and stratification of result shows a respiratory health symptoms effects of years to respirable dust exposure on lung function.

Abstrak

Pencemaran udara kini telah menjadi kebimbangan global terutamanya mengenai kesan yang merbahayakan kesihatan, tahap morbiditi yang meningkat, serta kadar kematian terutamanya bagi bahan zarah pencemar udara. Walau bagaimanapun, kajian yang membincangkan kesan dedahan debu dan zarah ternafaskan masih terhad bagi industri di Malaysia. Kajian ini telah menjurus kepada kandungan dan penyebaran zarah ternafaskan serta penentuan gejala-gejala kesihatan pekerja di dalam industri tertentu. Sebanyak tiga (3) kajian kes telah dilakukan untuk pengumpulan data. Bagi setiap kajian kes, beberapa lokasi persampelan dan pekerja yang dipilih secara rawak bagi penilaian tahap pendedahan debu dengan menggunakan kaedah pemantauan persekitaran peribadi. Beberapa siri pengukuran secara bacaan terus untuk pensampelan kawasan bagi kandungan zarah ternafaskan (PM_{10}), karbon dioksida (CO_2), suhu and kelembapan relatif juga telah dijalankan. Soal selidik telah diagihkan untuk mengenalpasti gejala berkaitan masalah kesihatan pernafasan dan disokong dengan ujian fungsi paru-paru dengan menggunakan alat *spirometer*. Hasil kajian menunjukkan kebanyakan pekerja di kilang berasaskan kertas telah terdedah dengan debu ternafaskan apabila Purata Pemberat Masa (TWA) yang diperolehi melebihi standard had dedahan yang dibenarkan iaitu 5 mg/m^3 dan 3 mg/m^3 oleh Pengurusan Kesihatan dan Keselamatan Pekerjaan (OSHA) dan Ahli Kebersihan Industri Kerajaan dan Konferen Amerika (ACGIH). Daripada 30 gejala, hanya lima gejala yang signifikan dengan tempoh dedahan. Terdapat 81.81% pekerja (kilang berasaskan kertas), 53.33% pekerja kilang kelapa sawit dan 65.63% pekerja di automotif berspiro normal. Pengurangan yang ketara dapat diperhatikan berdasarkan nilai min bagi Kapasiti Tekanan Vital (FVC), Isipadu Tekanan Ekspiratori (FEV_1) dan Nisbah Tekanan Ekspiratori (FEV_1/FVC) di kalangan pekerja. Kesimpulannya, fungsi paru-paru di kalangan pekerja yang terdedah telah terjejas dan stratifikasi keputusan menunjukkan bahawa terdapat kesan gejala kesihatan pernafasan terhadap dedahan debu ternafaskan kepada fungsi paru-paru.

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PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

List of Symbols

ACGIH	American Conference Governmental of Industrial Hygienists
AD	Aerodynamic Diameter
CI	Confidence Interval
CO ₂	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
FEV ₁	Force Expectoratory Volume in 1 Second
FEV ₁ /FVC	FEV ₁ to Forced Vital Capacity ratio
FVC	Force Vital Capacity
IAQ	Indoor Air Quality
NIOSH	National Institute of Occupational safety and Health
OSHA	Occupational Safety and Health Administration
PEF	Peak Expiratory Flow Rate
PEM	Personal Environmental Monitoring
PM	Particulate Matter
RH	Relative Humidity
RR	Relative Risk
SOCSSO	Malaysia Social Security Organization
TLV	Threshold Limit Values

TWA	Time Weighted Average
USEPA	United State Environmental Protection Agency
UTHM	Universiti Tun Hussein Onn Malaysia
WHO	World Health Organization



Chapter 1

Introduction

This chapter will explain about background of the study, the problem statement that arises from global and current issues, the objective, scope, limitation and the structure of thesis that will occur in this study.

1.1 Background of Study

Air pollution has become the major concern regarding to the harmful health effects, increase the morbidity and mortality risk toward exposed person especially for fine particulate air pollutant (Pope & Dockery, 2006; Pope *et al.*, 2002; Pope, 2000). Various studies have provided evidence that particulate matter (PM), especially PM_{2.5}, which represents the size range of particles likely to pass through the nose and mouth, is associated with a range of effects on human (Pope *et al.*, 2009; Wang *et al.*, 2006; Samet *et al.*, 2000). This fine particulate air pollutant, derived from both human and natural activities such as road and agricultural dust, tire wear emissions, wood combustion, construction, demolition works, and also from cement industry (Siddique *et al.*, 2011; Wani & Jaiswal, 2011; Zeleke *et al.*, 2011; Massey *et al.*, 2009; Simkhovich *et al.*, 2008).

Ambient particles includes coarse particles with aerodynamic diameter (AD) 2.5 to 10 μm (PM₁₀), fine particles (AD < 2.5 μm : PM_{2.5}) and ultrafine particles (AD < 0.1 μm ; Ultra-Fine Particles). The chemical composition of particles varies greatly and depends on numerous geographical, meteorological, and source-specific variables. Generally, ambient particles in clued inorganic

components (sulfates, nitrates, ammonium, chloride, trace metals) elemental and organic components (bacterial, spore, pollens) and adsorbed volatile and semi volatile organic compounds. In addition, ambient particles, when mixed with atmospheric gases (Ozone, Sulfur, and Nitric Oxides and Carbon Monoxide), can generate ambient aerosols.

1.2 Problem Statement

Air pollution is chronic public health problem with implications for children and adults worldwide. While much of the epidemiological evidence linking air pollution exposure for people and indoor air pollution from the used of biomass fuel in developing countries. The range of adverse health effects associated with exposure to air pollution has often been depicted as a pyramid Figure 1.1 below.

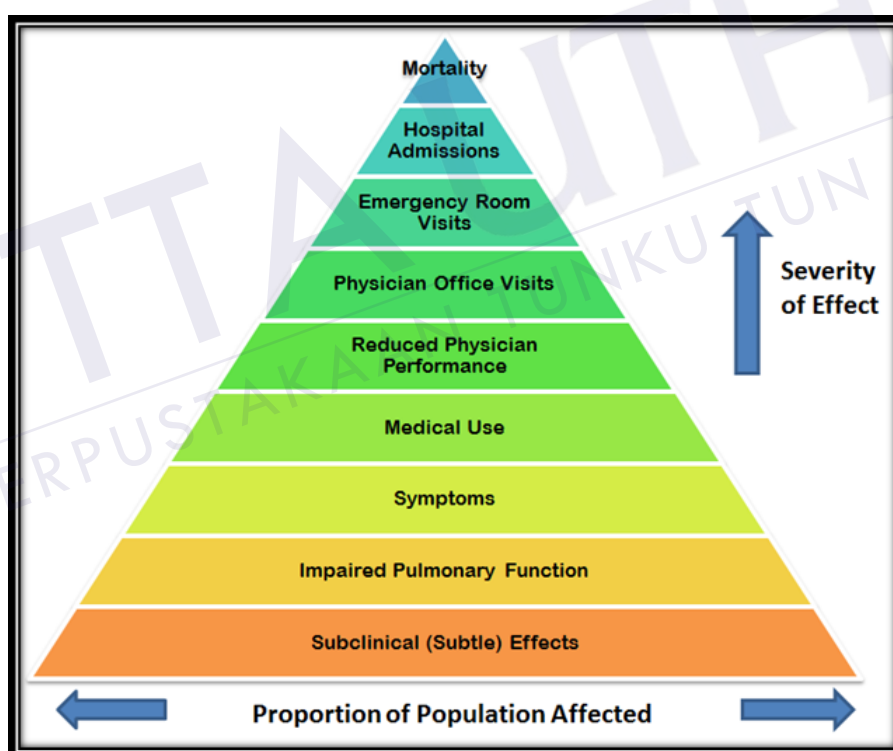


Figure 1.1: Pyramid of air pollution health effects (WHO, 2005).

In this formulation, a smaller proportion of the population is affected by the most severe health outcomes such as premature death, hospital admissions, and emergency-room visits; a greater proportion is impacted by conditions that affect quality of life, such as asthma exacerbation that result in work or school absences, and by sub clinical effects, such as slowed lung function growth in

childhood and accelerated development of atherosclerosis. The range of effects is broad, affecting the respiratory and cardiovascular systems and impacting children, the elderly, and those with pre-existing diseases such as Chronic Obstructive Pulmonary Disease (COPD) and asthma. The risk for various adverse health outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated (WHO, 2005).

Figure 1.2 below describes the range of health outcomes measured in epidemiological and human clinical studies. The impacts of short-term and long-term air pollution exposures have been studied extensively in North America and Europe for health endpoints toward the peak of the pyramid (i.e., premature death, hospital admissions, and emergency-room visits). More recent studies have examined the health effects of air pollution in low and middle-income countries where air pollution levels are the highest.

Short-term Exposure	Lung inflammatory reactions
	Respiratory symptoms
	Adverse effects on the cardiovascular system
	Increase in medication usage
	Increase in hospital admissions
	Increase in Mortality
Long-term Exposure	Increase in Lower respiratory symptoms
	Reduction in lung function in children
	Increase in chronic obstructive pulmonary disease
	Reduction in lung function in adults
	Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer

Figure 1.2: Health outcomes measured in studies of epidemiological and human clinical studies (WHO, 2006).

The scope of health concerns has broaden from an emphasis on total morbidity and mortality from respiratory causes, such as exacerbation of chronic respiratory diseases, including Chronic Obstructive Pulmonary Disease and asthma, and the respiratory health of children to several adverse cardiac and reproductive outcomes and impacts on susceptible sub populations, including those with pre-existing cardiopulmonary illnesses, children, and older adults.

Numerous recent single-city studies have expanded the health endpoints reported to be associated with particulate matter exposures, including indicators of the development of atherosclerosis with long-term exposure; indicators of changes in cardiac rhythm, including arrhythmia; effects on children and infants; markers of inflammation and effects on organ systems outside the cardiopulmonary systems ([USEPA, 2005](#)). The long-range implications for individuals of some of the intermediate markers of outcome remain to be established, but nonetheless they offer usual indicators of population health.

The evidence on airborne particulate matter and public health is consistent in showing adverse health effects at exposures experienced in cities throughout the world in both developed and developing countries. The epidemiological evidence shows adverse effects of particles associated with both short-term and long-term exposures. Adverse health effects have been demonstrated at levels just above background concentrations which have been estimated at 3–5 $\mu\text{g}/\text{m}^3$ in the United States and Western Europe for $\text{PM}_{2.5}$ ([WHO, 2006](#)).



Table 1.1: Selected Occupational Diseases by Causal Agent and Target Organ Respiratory System by SOCSO for the Year 2007 till 2009.

Occupational Disease by Causal Agent	No. of Cases Reported		
	2007	2008	2009
Dusts	167	107	56
Gases, vapors, fumes	34	36	34
Liquids not elsewhere classified	133	118	74
Chemicals not elsewhere classified	94	57	56
Others - dusts, gases, liquids, chemicals	189	91	87
Occupational Disease by Target Organ Resp. System	No. of Cases Reported		
	2007	2008	2009
Pneumoconioses caused by sclerogenic mineral	5	7	5
Bronchopulmonary diseases caused by hard metal	1	3	2
Bronchopulmonary diseases caused by cotton	0	1	1
Occupational asthma caused by sensitizing agents or irritant inherent to the work process	4	10	10
Extrinsic allergic alveolitis	0	2	2
Chronic obstructive pulmonary diseases	2	3	4
Diseases of lung, due to aluminum	0	2	17
Upper airways disorders	3	0	1
Any other respiratory diseases	9	21	11

Table 1.1 shows the selected number of occupational diseases by causal agent and target organ respiratory system cases reported to Malaysia Social Security Organization (SOCSO) for the year 2007, 2008 and 2009 (SOCSO, 2009, 2008, 2007). Although this numbers is in general and comprise of miscellaneous types of industries, the main concerns would be the poor health status of workers

were due to lack of awareness towards the causal agent of the diseases in their working environment and its target organ in human respiration systems. Poor safety and health precaution can bring to higher rates of occupational diseases.

Currently, there is still very limited study that discussed the effects of long time exposures of dust and particle matters in industry at Malaysia. So that, a baseline study due to the respiratory health effects on respirable dust exposure was done in selected small and medium-sized enterprise in Kluang, Johor which is represent the optimum risk of workers in Johor. The purpose of this study is to determine the workers exposure of respirable dust in their daily work and do survey about the health status of the workers.

1.3 Objectives of the Study

The objectives of this study are to:

- i. Monitors the concentration or levels of selected indoor air quality parameters and PM₁₀ in production or plant area.
- ii. Assess the measured personal exposure of respirable dust for workers if it comply with existing Permissible Exposure Limit guidelines and standards.
- iii. Determine the symptoms and the health effects by establish statistically relationship between time of exposure and their health status.

1.4 Scope of the Study

The scopes of this study are:

- i. The identification of respirable dust in the manufacturing industries. It was focus on manufacturing industry which believes can contribute to emission of dust especially respirable particulate matters. The designation of monitoring and standard of reference will be guided by worldwide standards which are United State: Environmental Protection Agencies (US EPA), National Institution of Safety and Health (NIOSH), World Health Organization (WHO) and in Malaysia we referred to Malaysia Code of Practice on Indoor Air Quality to assess the quality of indoor air within the office premises.

- ii. Determines the respiratory health status from the administered questionnaire to exposed personal such as workers in the office premises and production line workers.
- iii. The result of the answer will be analysed and result will demonstrate the health status of the exposed person. Hence, it will support by a spirometric lung test for the significant symptoms respondents.
- iv. The guidelines and standards utilized in this study are the Industrial Code of Practice on Indoor Air Quality (ICOP-IAQ, 2010), Malaysian Department of Occupational Safety and Health, Occupational Safety and Health Administration (OSHA) and American Conference and Governmental of Industrial Hygienists (ACGIH).
- v. A few small and medium-sized industries was selected in Kluang, Johor through the representative of the worse and high risk condition of occupational safety and health for SMEs.

1.5 Limitation of the Study

There are some limitations that will occur during this study and hence will carry forward for the next stage of study:

- i. This study will carried out within the industry only. For ambient monitoring, they study will carried out for the next level which it have to carry out for more than three years according to the US EPA method ([USEPA, 2005](#)).
- ii. The validity of the questionnaire's answer is relying on the veracity of the correspondent.
- iii. For personal sampling, it will be carried out only for eight (8) hours base on working hour.
- iv. The assessment were carried out on the dry day due to avoiding the bias condition of assessment.

1.6 Structure of the Thesis

This thesis is organized into five chapters. This chapter is the introduction. The purpose of this chapter is to provide information that is relevant to this study. This chapter discusses the research background, problem statement, objectives of the study, scope of the study, limitation of the study as well as the structure of the thesis.

Chapter two is the literature review. A detailed literature review of international and national background study that led to this study has been presented in this chapter. Literature review provides a solid historical background for support the study. Although there is little available data and standard on the respirable dust and respiratory health disease on workers for Malaysia industry, there is a great number of related literature concerning to respirable dust and particulate matter that adverse the human health that needs to be explored, such as: occupational health diseases, the time series study, acute effects, effects from chronic exposure, hospital admission, acute effects on lung function, respiratory symptoms, medication use and school, effects of long term exposure and possible health effects of particulate matter in human systems.

The third chapter is the methods and materials chapter, which explains the research methodology and materials used for conducting this study. This chapter describes the location of each sampling plant; research design; data collection for personal exposure monitoring, indoor air quality (IAQ) monitoring, respiratory health survey and spirometry lung function test and also the approach of measuring the relevant parameters for this study.

The results obtained are presented and discussed in the fourth chapter. The data were subjected to descriptive statistic whereby they will be tabulated into graphs. In addition, the data were further described in temporal and spatial distribution for better visualization. Then, it will be further analysed using inferential statistic to determine the correlation of respirable dust exposure and health symptoms also with the lung function test result.

A conclusion and recommendations chapter concludes the thesis. This chapter summarizes the major findings achieved in this study and provides recommendations for future work in this research area. Appendices provide all the relevant additional material and data.

Chapter 2

Literature Review

2.1 Small and Medium Sized Enterprises in the Malaysia Economy

2.1.1 Definition SMEs in Malaysia

Business systems in most countries consist of small, medium and large enterprise. Of these three kinds of enterprises, large enterprises openly dominate in many countries. In Malaysia, small and medium sized enterprises (SMEs) are overshadowed by corporations with the billions turnover and employees. Different people tend to have their own perceptions and interpretation of SMEs.

In general, however, small and medium enterprises in Malaysia have commonly been classified using fixed quantitative criteria such as number of employees, amount of capital, amount of assets and sales turnovers.

In 1996, the Small and Medium-sized Industry Development Corporation (SMIDEC) which officially replaced the former Small-scale Industry Division in the Ministry of International Trade and Industry developed definitions of SMEs in Malaysia. The SMIDEC characterized SMEs as:

- Small-sized business enterprise is “an enterprise with a paid-up capital of less than RM500,000 and employs full time employees not exceeding 50 persons.”

- Medium-sized business is “an enterprise with a paid-up capital of RM500,001 to RM2.5 million and employs full time employees of between 51 to 75 persons.”

In further recognizing the importance of the SMEs sector in the national economy in the Malaysian Government in 2004 establish the National SME Development Council. The Council which is headed by Honorable Prime Minister to oversee the healthy growth and development of the SMEs sector in Malaysia redefined SMEs into three broad categories based on different industries.

However, starting from 1st January 2014, the Prime Minister had announced a new definition for SMEs for Malaysia. The new definition is expected to result in more firms being classified as MSEs, particularly from the service sector. This will facilitate the country's transformation to a high income nation through the initiative under the SME Masterplan. As a result of the change in definition, the share SMEs to total establishments is expected to increase from 97.3% currently, to 98.5%. Table 2.1 is the definition for SME as follows:

Table 2.1: Definition of SMEs Offered by the National SME Council 2004 and 2014 for Malaysia. (Hashim 2007 and SMECORP, 2013)

Years	2004		2014	
Industry	Manufacturing, manufacturing-related services, and agro-based industry	Services, primary agriculture, and information and communication technology	Manufacturing, manufacturing-related services, and agro-based industry	Services, primary agriculture, and information and communication technology
Micro	Sales turnover of less than RM250,000 OR 5 full time employees	Sales turnover of less than RM200,000 OR less than 5 full time employees	Sales turnover of less than RM300,000 OR less than 5 employees	Sales turnover of less than RM300,00 OR less than 5 employees
Small	Sales turnover from RM250,001 to less than RM10 million OR 5 to 50 full time employees	Sales turnover from RM200,001 to less than RM1 million OR 5 to 50 full time employees	Sales turnover from RM300,001 to less than RM15 million OR 5 to less than 75 employees	Sales turnover from RM300,001 to less than RM3 million OR 5 to less than 30 employees
Medium	Sales turnover from RM10 mil to not exceeding RM25 mil OR 51 to 150 full time employees	Sales turnover from RM1 mil to not exceeding RM5 mil OR 20 to 50 full time employees	Sales turnover from RM15 mil to not exceeding RM50 mil OR 75 to not more than 200 employees	Sales turnover from RM3 mil to not exceeding RM20 mil OR 30 to not more than 75 employees

2.2 Particulate Matter

Particulate matters (PM) is an pollutant consisting of a mixture of particles that can be solid, liquid or both, are suspended in the air and represent a complex mixture of organic and inorganic substances. These particles vary in size, composition and origin. Their properties are summarized according to their aerodynamic diameter, called particle size. The measurements used at present are weights of two particular fractions:

- i. PM₁₀, particles with an aerodynamic diameter smaller than 10 μm , which may reach the upper part of the airways and lung.
- ii. PM_{2.5}, with an aerodynamic diameter smaller than 2.5 μm . these are regarded as more dangerous because they penetrate more deeply into the lung and may reach the alveolar region.

According to WHO 2004a, particles were divided into three groups as per shown in Figure 2.1.

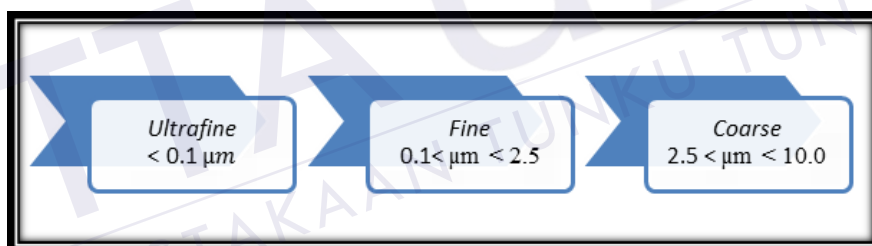


Figure 2.1: Particle Size (WHO, 2004a)

The fine and ultrafine fractions are more strongly associated with anthropogenic activities than the coarse fraction, which may contain for example wind blown dust. Most of the measurements, and all current air quality standards for particles, refer to the weight of the particles in different size ranges, such as PM₁₀ and PM_{2.5}. Both are measured in units of $\mu\text{g}/\text{m}^3$ the ultrafine particles (PM_{0.1}) represent only a fraction of measured PM₁₀-levels, but may make a considerable contribution to health effects. Apart from the fact that there are many more small particles for a given unit of weight they also cause more damage, since they can penetrate further into the airways and have a much larger surface area per unit weight. The number of particles should therefore provide a better measure of their harmfulness, but is more difficult to measure. As the particles are classed into two as per Figure 2.2.

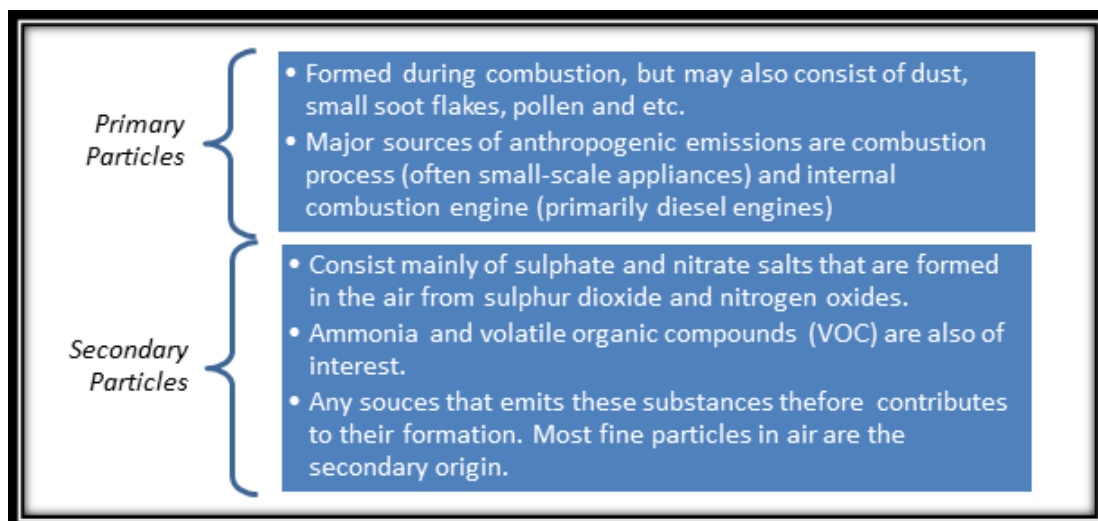


Figure 2.2: Particles Classes (WHO, 2004a)

Most Industrial dust contains particles of a wide range of sizes. The behaviour, deposition and fate of any particle after entry into the human respiratory system, and the response that it elicits, depend on the nature and size of particles. For the purpose of occupational hygiene, the consideration of concentration of dust present in different size fraction is very important. The American Conference and Governmental Industrial Hygienists (ACGIH) uses the terms inhalable, thoracic, and respirable particulate mass for Threshold Limit Values (TLV)s for particulates that are hazardous when inhaled.

- i. Inhalable Particulate Mass-TLVs: Fraction of airborne material that enters the nose and mouth during breathing, and is deposited in the respiratory tract.
- ii. Thoracic Particulate Mass-TLVs: Materials that are hazardous when deposited anywhere within the lung airways and the gas-exchange region (the lower airways passages).
- iii. Respirable Particulate Mass-TLVs: Particulates that are small enough to reach the gas exchange region and are hazardous only if they are deposited in lung region.

Figure 2.3 shows the parts of the respiratory system. It can divide in two systems; the upper airway passages and the lower airway passages. The upper airway passage includes the nose, nasal passages, mouth and the pharynx down to the vocal cords in the larynx. The lower airway passages start at the vocal

cords, extend down the trachea and continue all the way down to the small air sacs, (alveoli) at the end of every branch of the bronchial tree. The bronchial tree includes the trachea, the bronchus (branches of the trachea going to each lobe of the lung), and bronchioles (branches of the bronchi).

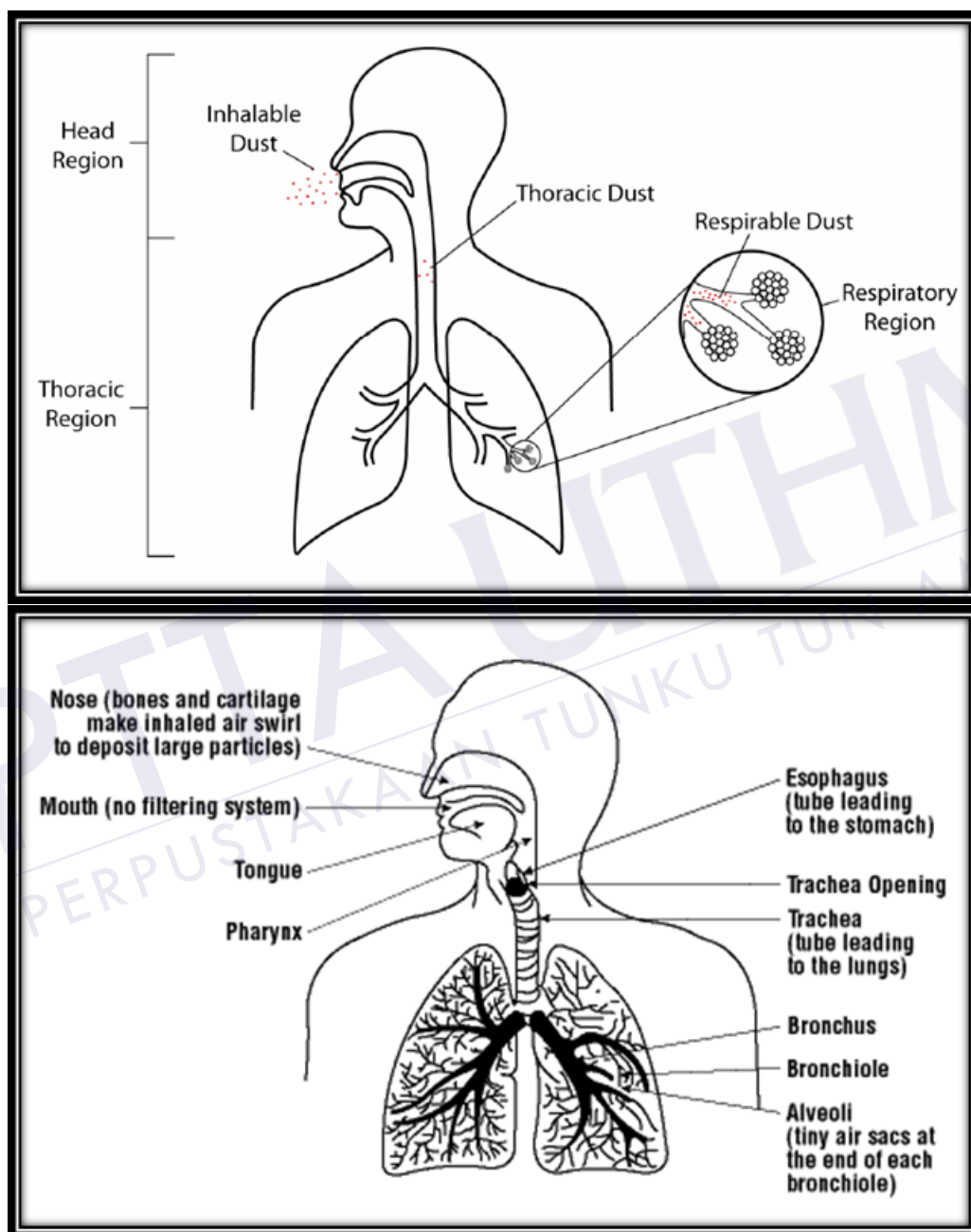


Figure 2.3: Regional Particle Deposition ([ACGIH, 1996](#)).

2.3 Guidelines and Standards

The World Health Organization, WHO, has until recently been unwilling to set any air quality guidelines for particles, since it is considered unlikely that a level will be found that does not have harmful effects. Instead, it has given a dose-response relationship that can be used to calculate for example how many people would be affected by a given level of particles in the air.

In the revised WHO air quality guidelines that were adopted in autumn 2005 (WHO, 2005c) it is stated that the link between exposure and effects can still be used, depending on local circumstances, to establish limit value. Some numerical values are also given to provide guidance on the concentrations at which increasing, and specified mortality responses due to PM are expected based on current scientific insights as per Table 2.2.

Table 2.2: Guidelines, target values and limit values (WHO, 2005c).

Particulate Matter's Guidelines	Max. 24-hour mean value ($\mu\text{g}/\text{m}^3$)	Annual mean value ($\mu\text{g}/\text{m}^3$)
PM₁₀		
WHO Guidelines	50 (99th percentile *)	20
EU limit value, from 2005	50 (96th percentile *)	40
Guide value, Sweden, from 2010	35 (90th percentile *)	20
Guide value proposed by IMM	30	15
PM_{2.5}		
WHO Guidelines (WHO 2005c)	25 (99th percentile *)	10
EU concentration cap from 2010	-	25
US limit value from 2010	65 ^(e)	15
Limit value, California	-	12
Guide value, Sweden, from 2010	20 (90th percentile *)	12
Limit value proposed by CAFE	-	12-20

By referring to Table 2.2, National Institute of Environmental Medicine (IMM) have set the lowest limit value for the PM₁₀ concentration respectively. As per US limit value for PM_{2.5}, Environmental Protection Agency (EPA) was recommended them to reduce the mean value from 65 to 35 $\mu\text{g}/\text{m}^3$ by according

to the proposal by EPA in December 2005 (WHO, 2005c). They also provide a dose-response link as per Figure 2.4 for a better view of understanding.

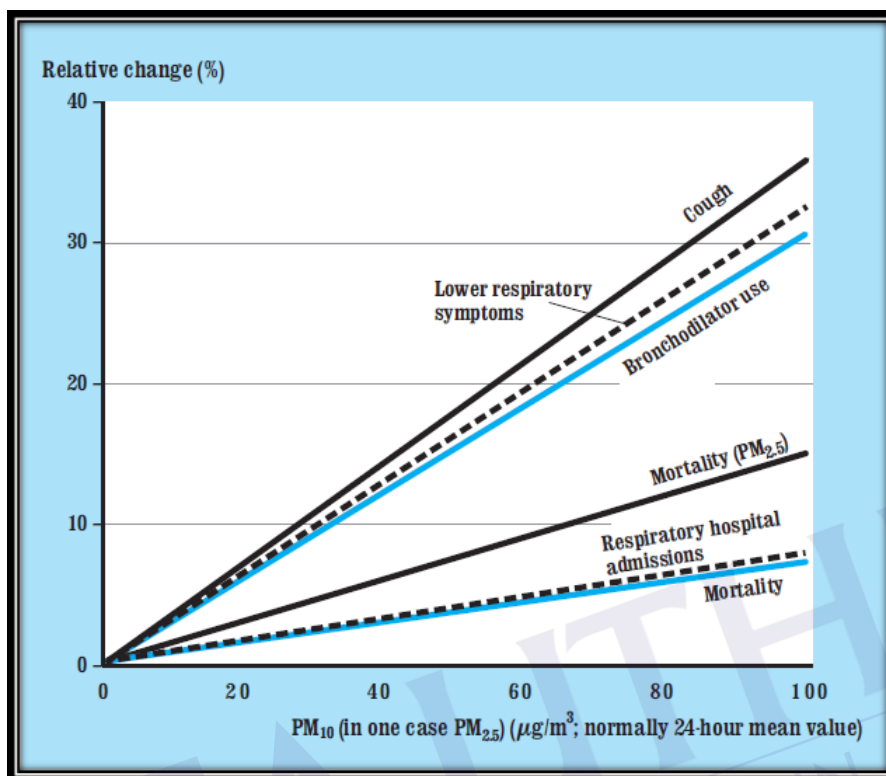


Figure 2.4: Link between particles in ambient air and effects on health. Dose response link at exposure below $20 \mu\text{g}/\text{m}^3$ is however uncertain (WHO, 2000).

A working group under Clean Air For Europe (CAFE) programme reported in a position paper (CAFE, 2004) that for health reasons, it should aim for a reduction in annual mean concentration of $\text{PM}_{2.5}$ to levels of around $10 \mu\text{g}/\text{m}^3$ or lower. In the short term, by 2010, the group recommended that limit values in the range of $12\text{--}20 \mu\text{g}/\text{m}^3$ should be considered. The percentile (*) is a statistical measure that indicates how many times (in this case days) a limit value may be exceeded. For example:

- i. 90th percentile = 37 exceedances per year.
- ii. 96th percentile = 35 exceedances per year.
- iii. 98th percentile = 7 exceedances per year.
- iv. 99th percentile = 4 exceedances per year.

2.4 Occupational Health Diseases

Epidemiological studies have traditionally played an important role in deriving guideline values for airborne suspended particulate matter. Current concerns about the health effects of airborne particles are largely based on the results of recent epidemiological studies suggesting effects on mortality and morbidity at very low levels of exposure.

This section provides a brief review of epidemiological studies relating airborne particulate matter exposure to various health endpoints. In view of the uncertainty of the current relationships of black smoke and total suspended particulates to mortality and morbidity, no studies with measurements of these components alone will be included. The emphasis is on studies with measurement data on PM₁₀, PM_{2.5} and/or sulfate and acid aerosol fractions, and on studies that permit some separation of the effects of particulate matter from those of other pollutants in the mixture. Not surprisingly, the effects of particulate matter on health have been reviewed repeatedly in the past few years (U.S.EPA., 1996; Brunekreef *et al.*, 1995; Pope *et al.*, 1995b; Dockery & Pope, 1994; Schwartz, 1994a). The information given here is based on the recent reviews as well as on an evaluation of the original papers themselves.

2.4.1 Time-Series Study

The use of time-series studies to document the acute effects of particulate matter on health has increased substantially since the 1987 edition of Air quality guidelines for Europe (WHO, 2000). Time series studies relate the development in time of air pollution and some health variable such as daily mortality, hospital admissions, etc. Usually, routinely collected data on air pollution levels are used as exposure variables, although in some instances, air pollution monitoring programmes have been implemented specifically for use in time-series studies. The sources of health data are more varied: for mortality, routine statistical data are usually used; for hospital admissions, data are sometimes available in central registries covering large areas, but sometimes have to be obtained from individual hospitals; when “panels” of healthy or diseased subjects are being studied, the health data are usually obtained by the investigators from the participants in the study using diaries, lung function measurements, etc.

There are several methodological problems involved in the analysis of time-series studies. One of them is the fact that the health variables usually exhibit some pattern over time (e.g. higher mortality in winter or during heat waves) which needs to be accounted for before air pollution effects can be studied. In some long time-series studies (spanning several years), long-term time trends in health data have been observed in addition to seasonal cycles. As the weather may affect both air pollution concentrations and health, the most appropriate way to adjust associations between air pollution and health for weather influences has been a matter of some debate.

The great advantage of time-series studies is that they focus on variation with time over relatively short periods of days to weeks at most. Over such short periods, many personal characteristics such as age, smoking habits, etc. do not change, so that they can be ignored as potential confounders. Also, the variation in time of short-term average air pollution concentrations is often much greater than the variation in space of the long-term average pollution concentrations that form the basis of studies of long-term effects of air pollution on health (Dockery & Brunekreef, 1996). This is important because sufficient variation in exposure is a prerequisite in any analytical epidemiological study.

2.4.2 Mortality: Acute Effects as Suggested by Time-Series Study

Many recent studies have addressed the relationship between daily variations in particulate air pollution and mortality at low levels of exposure.

Pope *et al.* studied daily mortality in relation to PM₁₀ pollution in Utah Valley for the period from April 1985 to December 1989 (Pope *et al.*, 1992). A local steel mill is a major source of particulate air pollution in the area, in which concentrations of ozone, sulfur dioxide and nitrogen dioxide are generally low. Total, respiratory and cardiovascular mortality were found to be related to the 5-day moving average PM₁₀ concentration, including the concurrent day. The 24-hour average concentrations ranged up to 365 µg/m³, with 5-day moving average concentrations of up to 297 µg/m³ in the observation period; a graphical and tabular analysis suggested that effects on mortality could be seen at levels of < 100 µg/m³. The estimated increase in total daily mortality was 16% for each 100 µg/m³ increase in the 5-day moving average PM₁₀ concentration (which would translate into a 13% increase per 100 µg/m³ when expressed for 24-hour

average PM₁₀ concentrations).

Dockery et al. published an analysis of daily mortality in St Louis, MO, and the counties surrounding Kingston/Harriman, TN (Dockery & Brunekreef, 1996). During the period of observation (September 1985 to August 1986), 24-hour average PM₁₀ levels ranged from 1 to 97 µg/m³ in St Louis and from 4 to 67 µg/m³ in Kingston/Harriman. Even at these low levels, the relationship between PM₁₀ and mortality was statistically significant in St Louis. The estimated coefficient for Kingston/Harriman was not significant, but of similar magnitude. A number of gaseous air pollution components (sulfur dioxide, nitrogen dioxide, ozone) were also evaluated but none of these was found to be significantly associated with mortality.

The relationship with PM₁₀ was stronger than with PM_{2.5}, which was stronger than with sulfates, which was stronger than with hydrogen ion. The estimated effect on total mortality was a 16% increase for each 100 µg/m³ increase in the 24-hour average PM₁₀ concentration on the previous day, and a 17-23% increase for each 100 µg/m³ increase in the 24-hour average PM_{2.5} concentration on the previous day.

Schwartz (1993) studied the relationship between PM₁₀ and daily mortality in Birmingham, Alabama over the period 1985–1988. PM₁₀ averaged 48 µg/m³, and the highest 24-hour value was 163 µg/m³. Daily mortality was found to increase with increasing PM₁₀ concentrations. Relative risks for chronic lung disease and cardiovascular deaths were higher than for death from other causes. The relationship remained when all days with PM₁₀ values of > 150 µg/m³ were excluded. Data on other pollutants were not reported. The relative risk for total mortality was an 11% increase for each 100 µg/m³ increase in the PM₁₀ concentration, averaged over the previous 3 days. The published data do not permit estimation of the effect expressed per 24- hour average concentration.

Other studies have been reported using other measures of airborne particulate matter such as black smoke, total suspended particulates or the coefficient of haze for reviews of studies published until about 1994 (Pope et al., 1995b; Dockery & Pope, 1994; Schwartz, 1994a).

2.4.3 Mortality: Effects from Chronic Exposure as Suggested by Cross-Sectional and Cohort Studies

Data on chronic effects of airborne particulate matter on mortality come from cross-sectional studies, comparing air pollution exposure and mortality rates between locations and from cohort studies documenting the mortality experience of differentially exposed subjects over time.

An example of a cross-sectional analysis of the association between mortality rates and airborne particulate matter is a study by Özkaynak and Thurston (Azkaynak & Thurston, 1987). They compared US 1980 mortality rates with various measures of exposure to airborne particulate matter. In this analysis, sulfates, fine particles, inhalable particles and total suspended particulates were found to be associated, in decreasing order, with total mortality, after adjustment for a number of socioeconomic predictors of mortality. An example from Europe is a study reported by Bobak and Leon from the Czech Republic (Bobak & Leon, 1992). These authors correlated infant mortality with particulate matter air pollution over the years 1986–1988. Annual geometric mean particle concentrations were $68.5 \mu\text{g}/\text{m}^3$ overall. Concentrations were subdivided into quintiles, the highest quintile relating to areas with annual mean particle concentrations above $84.7 \mu\text{g}/\text{m}^3$.

Post neonatal mortality was found to increase almost monotonically with particle concentrations, the highest quintile having a relative risk of 1.42. The estimated risk ratios were higher for post neonatal respiratory mortality. Particle concentrations were reported as PM_{10} , and the analysis was made with adjustment for a number of socioeconomic indicators, proportion of total births outside marriage and abortion rate, as well as annual mean sulfur dioxide and nitrogen dioxide concentrations. The general criticism of such studies is that they are “ecological” in comparing aggregate data on mortality with aggregate data on pollution, with no possibility of taking individual confounders into account.

Recently, however, the suggestive evidence coming from cross-sectional studies has been supplemented with data from two cohort studies. Dockery *et al.* (Dockery *et al.*, 1993) followed a cohort of more than 8000 adults living in six US cities with varying levels of air pollution exposure for periods of 14–16 years, between 1974 and 1991. After adjustment for age, sex, smoking, education, occupational exposure and body mass index, a significant relationship was found between exposure to fine particles and survival. The closest association was

found for $\text{PM}_{2.5}$ and sulfate, with less clear relationships with total suspended particulates, aerosol acidity (only measured for one year in each city) and sulfur dioxide, and virtually no relationship with ozone. The estimated effect was a mortality-rate ratio of 1.26, comparing the most polluted city (Steubenville) with the least polluted city (Portage).

The mean fine particle concentrations ranged from 11.0 to 29.6 $\mu\text{g}/\text{m}^3$ with little change over the study period (fine particle measurements were reported for the 1980–1988 period). Compared to, for example, the mortality-rate-ratio associated with active smoking in this cohort (1.59), this represents a sizable effect of particulate air pollution on survival. Pope et al. (Pope *et al.*, 1995a) analysed data from a large cohort study conducted by the American Cancer Society since 1980. Pollution data from 151 US metropolitan areas were linked to 8 years of follow-up data from about 500 000 subjects.

After adjustment for age, sex, race, active and passive smoking, occupational exposure, education, body mass index and alcohol intake, a significant association between fine particulate air pollution exposure and survival emerged. Comparing the highest polluted area with the lowest polluted area, an adjusted mortality-rate ratio of 1.17 was found for $\text{PM}_{2.5}$.

2.4.4 Hospital Admission

Schwartz *et al.* studied hospital emergency room visits for asthma in Seattle, Washington, over a 13-month period from September 1989 to September 1990 (Schwartz *et al.*, 1993). The 24-hour average PM_{10} concentrations ranged from 6 to 103 $\mu\text{g}/\text{m}^3$. Asthma visits by subjects under 65 were significantly associated with the PM_{10} concentration measured on the previous day, after adjustment for weather variables and a number of other potential confounders.

A graphical and tabular analysis suggested that an increase in asthma visits could be observed at levels below 24 $\mu\text{g}/\text{m}^3$. Sulfur dioxide and ozone were not found to be related to asthma visits. Sulfur dioxide concentrations never exceeded 81 $\mu\text{g}/\text{m}^3$, and ozone data were only available for a 4-month period within the period of observation. The estimated relative risk was 1.12 for a 30 $\mu\text{g}/\text{m}^3$ increase in the 4-day average PM_{10} concentration and 1.11 for a similar increase in the 24-hour average concentration.

Using hospital data from Birmingham, Alabama for the years 1986–1989,

Schwartz ([Schwartz, 1994c](#)) reported a significant relationship between PM₁₀ concentrations and hospital admissions for pneumonia and chronic obstructive pulmonary disease in the elderly. The mean PM₁₀ concentration was 45 µg/m³ with a 90-percentile of 77 µg/m³. For each 100 µg/m³ increase in 24-hour average PM₁₀, admissions for pneumonia increased by 19% and for chronic obstructive pulmonary disease by 27%. Excluding all days with PM₁₀ levels above 150 µg/m³ did not change the effect estimates.

Schwartz ([Schwartz, 1994b](#)) examined associations between daily PM₁₀ and hospital admissions for respiratory disease in Minneapolis-St Paul, MN. Data on hospital admissions in persons aged 65 years and older were obtained for the years 1986–1989 by admission date for pneumonia and chronic obstructive pulmonary disease. Classification was by discharge diagnosis. Poisson regression was used to control for time trends, seasonal fluctuations and weather.

PM₁₀ was a risk factor for pneumonia admissions (relative risk (RR) = 1.17, 95% confidence interval (CI) = 1.02–1.33) and chronic obstructive pulmonary disease admissions (RR = 1.57, 95% CI = 1.20–2.06). Ozone was also associated with pneumonia admissions. The PM₁₀ relative risk is for an increase of 100 µg/m³ in daily PM₁₀.

Thurston and his group ([Thurston *et al.*, 1994](#)) examined air pollution and daily hospital admissions for respiratory causes in Toronto, Ontario. PM_{2.5} samples were collected daily at a central city site during July and August of 1986, 1987 and 1988 and were subsequently extracted and analysed for daily particulate phase aerosol strong acidity (hydrogen ion) and sulfates. Daily counts of respiratory admissions to 22 acute care hospitals and daily meteorological and environmental data on ozone, total suspended particulates and PM₁₀ were also obtained.

After controlling the temperature, ozone, hydrogen ion and sulfates were significantly associated with respiratory and asthma admissions. Comparing various particle parameters, the authors found that associations decreased in strength from hydrogen ion to sulfates to PM_{2.5} to PM₁₀ to total suspended particulates, indicating that particle size and composition are important in defining the adverse human health effects of particulate matter. On average, summer-time haze was associated with 24% of all respiratory admissions (21% with ozone, 3% with hydrogen ion). On peak pollution days, however, hydrogen ion had the highest relative risk estimate (1.5 at 391 nmol/m³ hydrogen ion) and summer-time haze was associated with roughly half of all respiratory admissions.

2.4.5 Acute Effects on Lung Function, Respiratory Symptoms, Medication Use and School

Pope *et al.* studied daily changes in lung function and acute respiratory symptoms in a panel of subjects living in Utah Valley, UT, where a large steel mill causes increased concentrations of PM₁₀ but not of other measured pollutants (Pope *et al.*, 1991). Subjects included a sample of wheezing school children and a sample of asthma patients aged 8–72 years. The observation period included the winter months of 1989–1990; 24-hour PM₁₀ concentrations ranged from 11 to 195 µg/m³, and on only two days, a concentration of 150 µg/m³ was exceeded. The peak expiratory flow rate (PEF) was found to be related to PM₁₀ concentrations in the preceding days. Respiratory symptoms and asthma medication use increased with increasing PM₁₀ concentrations in the school-based sample of children.

In the asthma patients, only the use of extra asthma medications was found to be associated with PM₁₀. After excluding the two days with PM₁₀ concentrations above 150 µg/m³, the highest PM₁₀ concentration was 114 µg/m³. The relationship between PEF and PM₁₀ remained unchanged after this exclusion.

Pope and Dockery studied panels of symptomatic and asymptomatic children in Utah Valley in the winter of 1990–1991 (Pope & Dockery, 1992). 24-hour PM₁₀ concentrations ranged from 7 to 251 µg/m³. On 14 days during the study period, a level of 150 µg/m³ was exceeded. PEF was decreased, and the reporting of respiratory symptoms was increased in both panels when PM₁₀ concentrations increased. All observations from days with or immediately following days with PM₁₀ concentrations above 150 µg/m³ were excluded from some of the analysis. The results remained essentially unchanged. A tabular analysis further suggested that PEF was decreased, and respiratory symptoms were increased at PM₁₀ concentrations exceeding 39 µg/m³.

In another study from the Utah Valley, Ransom and Pope investigated elementary school absences in relation to PM₁₀ pollution over a period of six years, 1985–1990 (Ransom & Pope, 1992). The highest PM₁₀ concentration observed in this period was 365 µg/m³, and exceeded 150 µg/m³ on approximately 10 days each year. School absenteeism was found to be related to 4-week moving average PM₁₀ concentrations, after adjustment for weather variables and a number of other potential confounders. The relationships generally remained after excluding observations obtained on days when PM₁₀ had exceeded 150 µg/m³ within the previous four weeks.

2.4.6 Effects of Long-Term Exposure on Lung Function and Respiratory Symptoms

As with mortality, it is important to consider not only the short-term, but also the long-term effects of particles on respiratory health. Three recent reports indicate associations between aggregate data on lung function and chronic respiratory disease on the one hand and airborne particles on the other hand. Chestnut *et al.* (Chestnut *et al.*, 1991) used lung function data collected among 6900 adults living in 49 different locations in the USA during the first National Health and Nutrition Examination Survey (NHANES I) between 1971 and 1975. FVC was found to decrease with increasing annual average total suspended particulate levels with an apparent threshold at about $60 \mu\text{g}/\text{m}^3$.

Schwartz (1993) used chronic respiratory disease data from the same source. After adjustment for smoking, occupational exposure and a number of other risk factors, the risk of chronic bronchitis increased with increasing particulate concentrations, with no apparent threshold. A Swiss cross-sectional study also found an effect of PM_{10} on FVC and FEV1 (Ackermann-Lieblich *et al.*, 1997).

In contrast to the studies on short-term health effects, there are few studies documenting morbidity effects of long-term exposure to PM_{10} and other measures of fine particulate matter. Data from the Harvard Six Cities Study indicate increased respiratory illness rates among children exposed to increasing concentrations of total suspended particulates, sulfates and hydrogen ion as indicators of exposure to fine particulate matter (Ware *et al.*, 1986).

Relative risk estimates suggested an increase of 11% in cough and bronchitis rates for each $10 \mu\text{g}/\text{m}^3$ increase in annual average total suspended particulate concentration. There was no clear relationship between airborne particulate matter exposure and lung function in this population. In a survey of respiratory symptoms among children in 24 communities in the USA and Canada, the incidence of bronchitis was found to increase by 29% for each $10 \mu\text{g}/\text{m}^3$ increase in annual average PM_{10} concentration though the relation with other measures of particulate matter was better pronounced (Raizenne *et al.*, 1996).

2.4.7 Possible Health Effect of Particulate Matter in Human Systems

The epidemiological studies have provided evidence that there are serious hazards associated with the human exposure to environmental levels of particulate matter found in the urban centres at concentrations below the acceptable particulate matter levels ([USEPA, 2005](#)).

Even though various reactions to components of environmental particulate matter have been hypothesized to contribute to the reported health hazards, the related published toxicology and controlled human clinical studies have not pinpointed an acceptable mechanism that could explain how such low levels of particulate matter concentration could cause the health hazards reported in the epidemiological studies.

However, the toxicological studies tend to show that particles become more toxic per mass unit with decreasing size. This makes Ultra-Fine Particles (UPF) a primary target for further research. Consequently, our attention turns to the surface area or the particle number, rather than mass concentration ([M. Politis, C. Pilinis, 2008](#)).

The studies on particle mass concentration (PM_{10} and $PM_{2.5}$) show that there is no lower limit for particle mass below which is no health danger. This is presented in the guidelines of the World Health Organization for air quality ([WHO, 2005b](#)), which has a linear relationship between PM_{10} and $PM_{2.5}$ with various health indicators (including mortality, hospital admissions, bronchodilators use, symptom aggravation, cough and peak expiratory flow) for concentration levels from 0 to 200 $\mu g/m^3$.

To summarize part of the aforementioned knowledge, the following Figure 2.5 includes the systems in which the particles could be accumulated, most of the known signs, symptoms and diseases that born or altered by human exposure to suspended particulate matter, and especially, ultrafine particles.

From the above comprehensive literature review, it can conclude that there is a correlation between particulate matters and alterations in morbidity and mortality indices because of respiratory and cardiac effects in the elderly and susceptible groups. There is also a correlation with increased proportion of asthma episodes and hospital admissions. Ultrafine particle (UFP) exposure could be responsible for increased medicine use, missed work-hours and school

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